Alignment with Tracks

Jim Pivarski

Alexei Safonov

Texas A&M University

Károly Banicz

US-CMS

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Since last time...

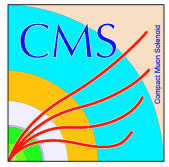
- CSC Overlaps alignment with beam-halo approved for public
- Cleanly separated $\vec{B}(\vec{x})$ and dE/dx errors from misalignments
- More complete understanding of residuals (non-Gaussian tails)
- Began diagnostics of track-source bias in real data
- Aligned about half of the DT chambers relative to tracker in CRAFT

In progress (concurrently)...

- Aligning CSCs relative to barrel using the same CRAFT data
- Well-organized software framework for push-button CRAFT-2009
- 50 pb^{-1} Monte Carlo study with updated procedure and systematics
- CMS Note on HIP procedure and results (barrel+endcap, cosmics+MC)

At the end of this talk, I'll give a timeline

Outline for this talk



1. Developments from CRAFT experience
   - optimizing procedure to distribution of cosmic rays
   - alignment in the presence of $\vec{B}(\vec{x})$ and dE/dx errors
   - residuals from single-scattering
   - studies of track-source bias

2. Global alignment of DT chambers
   - cross-checks: not just a residuals minimization

3. Preliminary CSC alignment plots from Monte Carlo (statistical only)

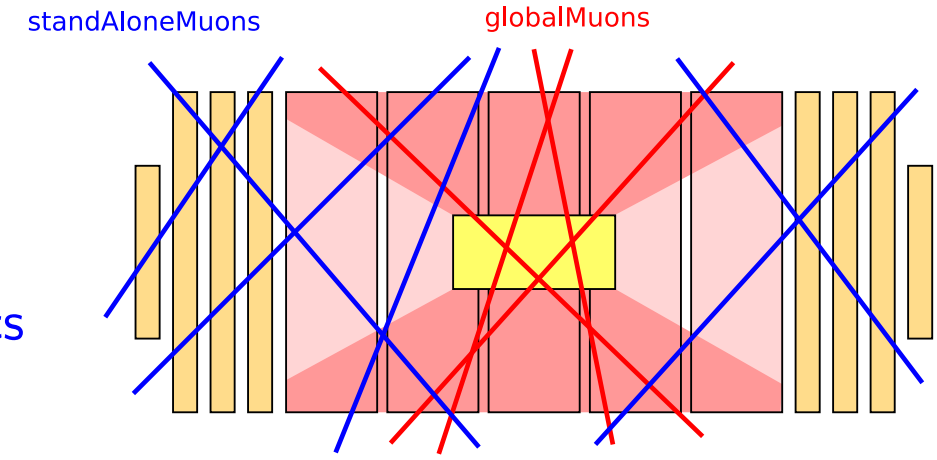
4. Steps toward muon geometry for first collisions and 200 pb^{-1}

Cosmic ray track distribution

- We knew from MC that few cosmics would link endcap to tracker
  - standard (collisions) alignment procedure fits tracks with silicon tracker and propagates them to each muon chamber
  - only about half of the DTs and "few if any" individual CSCs can be aligned this way in a several-week cosmic ray run
- Large structures (wheels and disks) can be aligned with small statistics
  - but ϕ asymmetry hilights some chambers at expense of others
  - whole wheel would rotate to align one or two chambers!

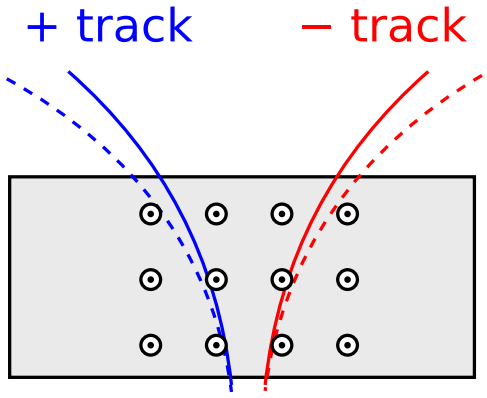
Global alignment plan:

1. Align DT chambers individually to tracker
2. Complete and cross-check barrel with standAlone cosmics
3. Align CSC chambers individually to barrel



$\vec{B}(\vec{x})$, dE/dx and misalignment

- Residuals from misalignment are independent of the tracks used to measure it
- Residuals from $\vec{B}(\vec{x})$ and dE/dx errors flip sign with the charge of the muon and depend on p_T

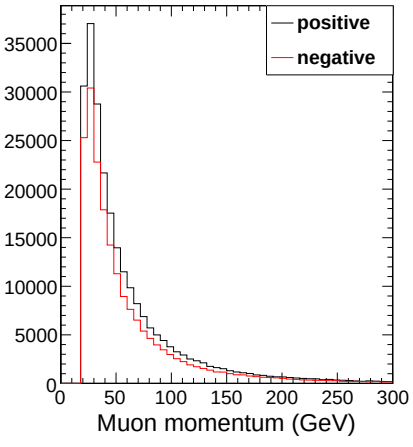


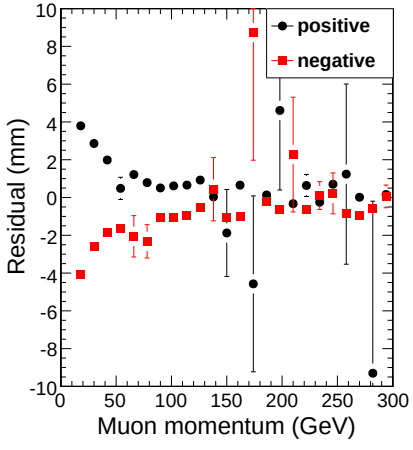
wrong B-field or dE/dx

Two-bin approach:

Fact: momentum spectra for $+$ and $-$ charges are proportional

Fact: $\vec{B}(\vec{x})$ and dE/dx effects are both antisymmetric with q

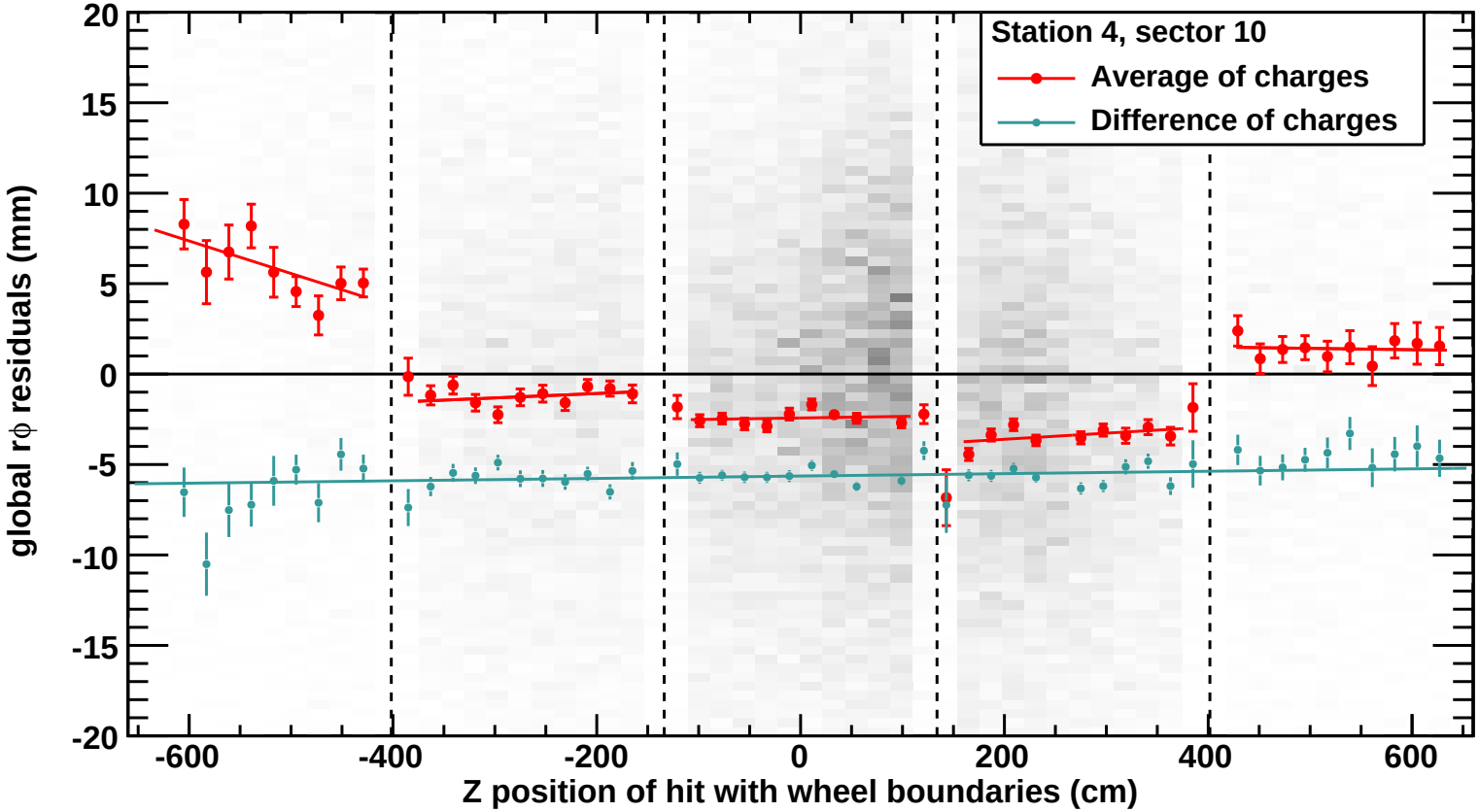




- Find peak of residuals in two charge bins: R_+ and R_-
- Average $(R_+ + R_-)/2$ is sensitive to misalignment only
- Difference is sensitive to $\vec{B}$ error and dE/dx errors only

Demonstration in MB4

- Station 4 has the largest $\vec{B}$-field errors: plot residuals across barrel
- The misalignment breaks cleanly at the chamber boundaries
- The $\vec{B}$-field error is independent of chamber



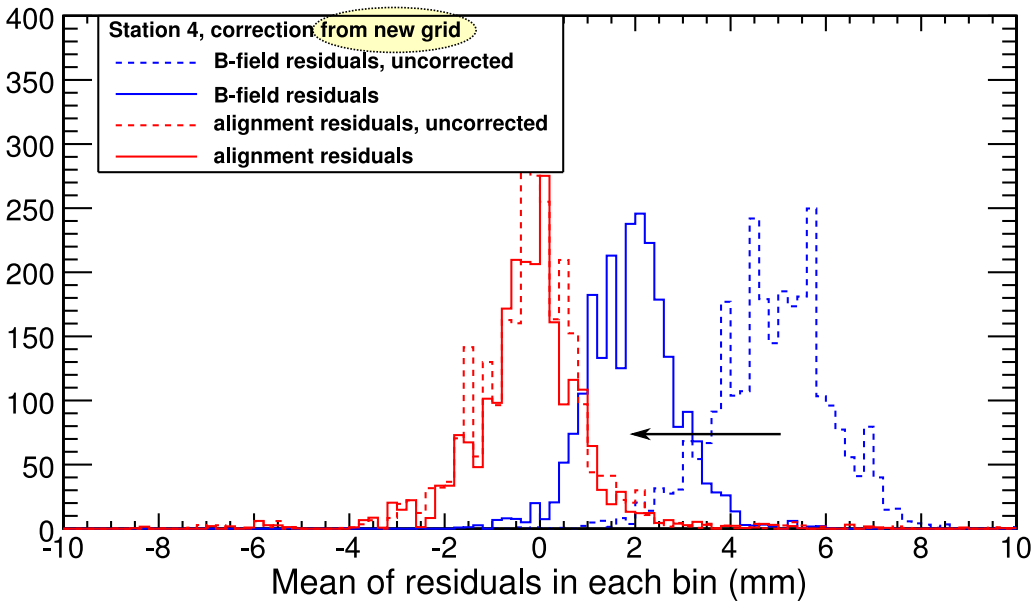
grey background is the raw 2-D residuals distribution

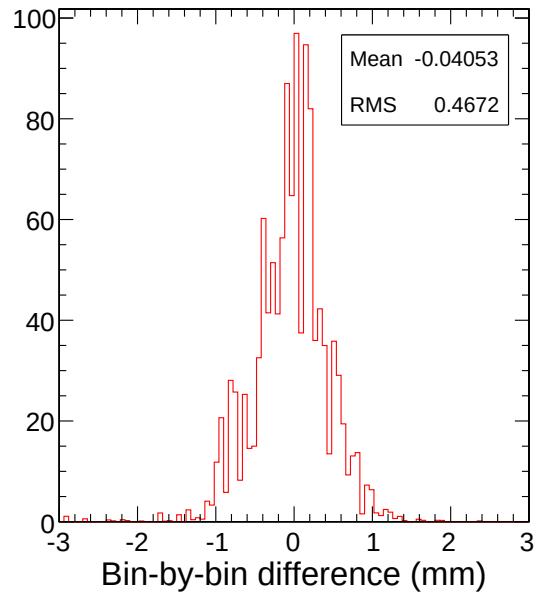
linear fits are only a guide for the eye: not used in alignment!

Insensitivity to $\Delta\vec{B}(\vec{x})$

- $\vec{B}(\vec{x})$ simulation improved by increasing TOSCA grid volume
  - main problem was not missing material (e.g. green structure)
  - simulation's universe was too small: field lines were cramped
  - better but not perfect agreement with tracks and Hall probes
- Re-calculate alignment plots to test insensitivity to new map and cross-check correctness of new map
  - left: histogram of bins from the previous plot (for all sectors)
  - right: how each bin changes when new field is applied

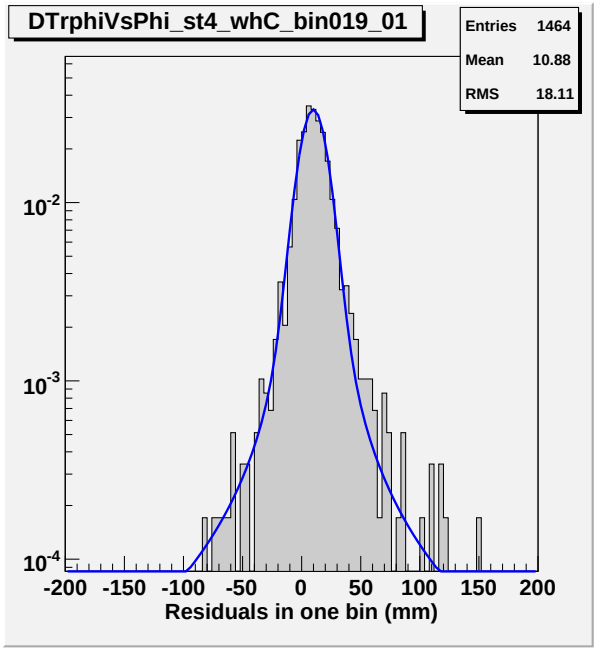
statistical errors in bins are $\mathcal{O}(0.5$ mm$)$





Residuals and *single* scattering

barrel data



- Single scattering process has a power-law distribution, while multiple scattering and experimental resolution are Gaussian
- Peak of residuals distribution should not be computed from the mean: it would be pulled by scattered "outliers"
- Model process as Lorentzian-Gaussian convolution (Voigt distribution):

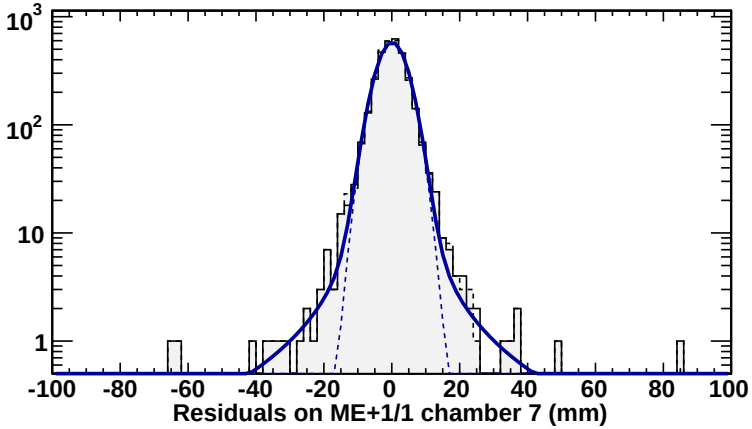
$$f(x) = \int_{-\infty}^{\infty} \frac{1}{\pi} \frac{\Gamma/2}{(x - \xi - x_0)^2 + (\Gamma/2)^2} \times \frac{1}{\sqrt{2\pi}\sigma} \exp\left(\frac{-\xi^2}{2\sigma^2}\right) d\xi$$

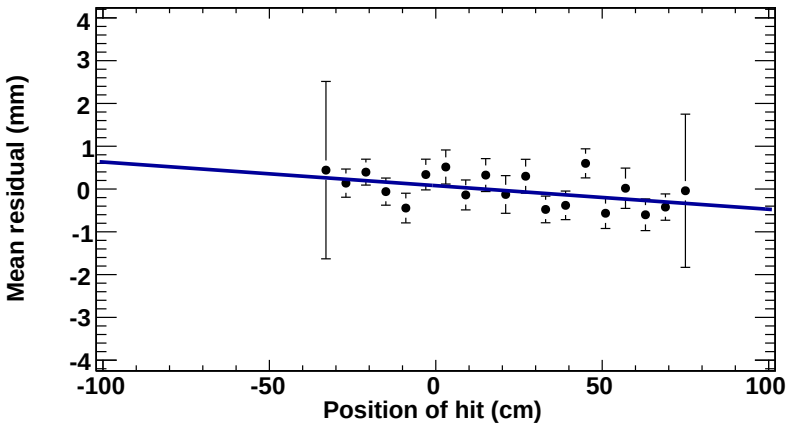
- Determine peak (alignment correction) from x_0 of unbinned fit
  - regular mean ($\sum x_i/N$) = center of an unbinned Gaussian fit
  - this is the same thing, but with tails
  - "outliers" contribute far less to $f(x)$ log-likelihood than Gaussian

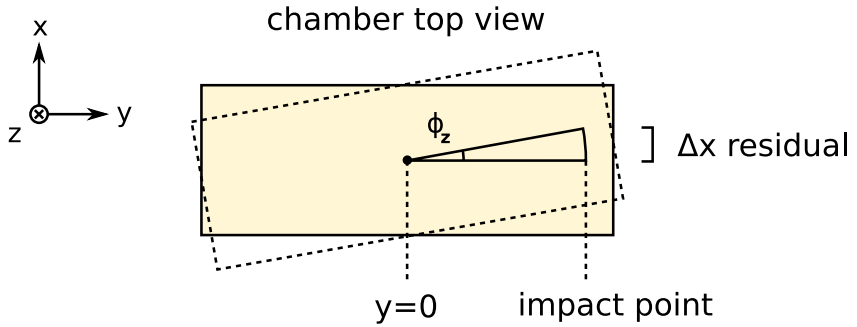
Fitting more parameters

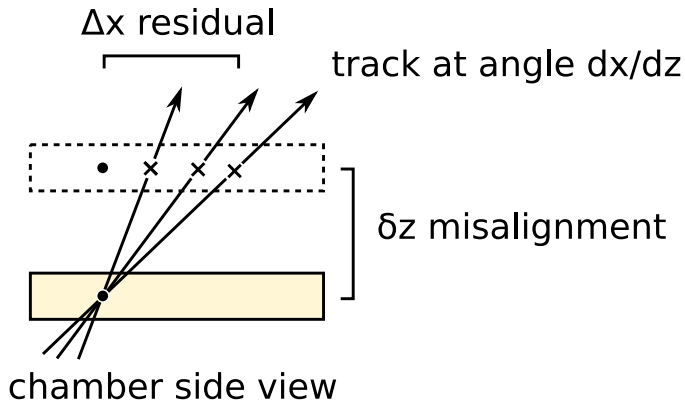
- Center of peak = translation
- Rotations and out-of-plane translations introduce linear trends in residuals

endcap Monte Carlo









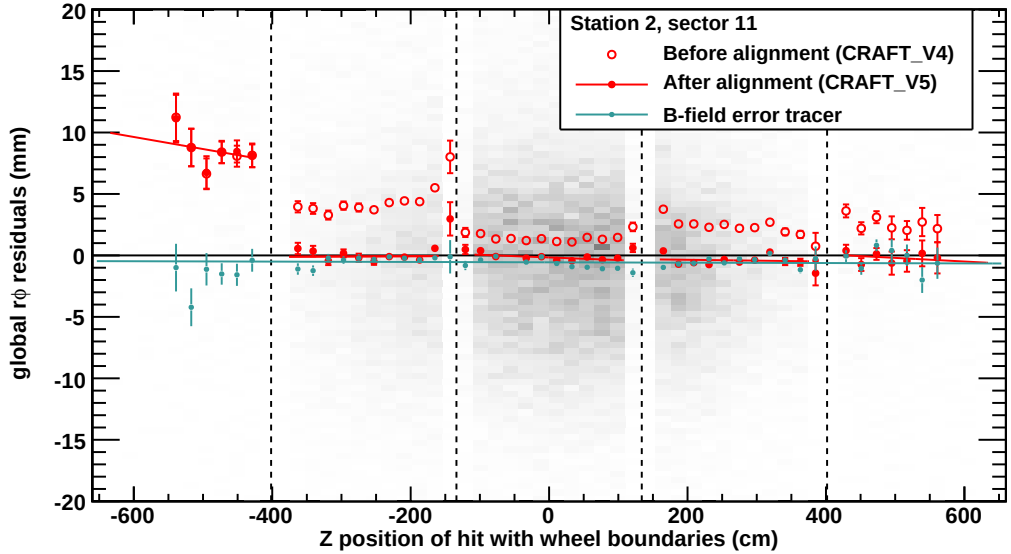
- Determine multiple parameters from simultaneous fit:

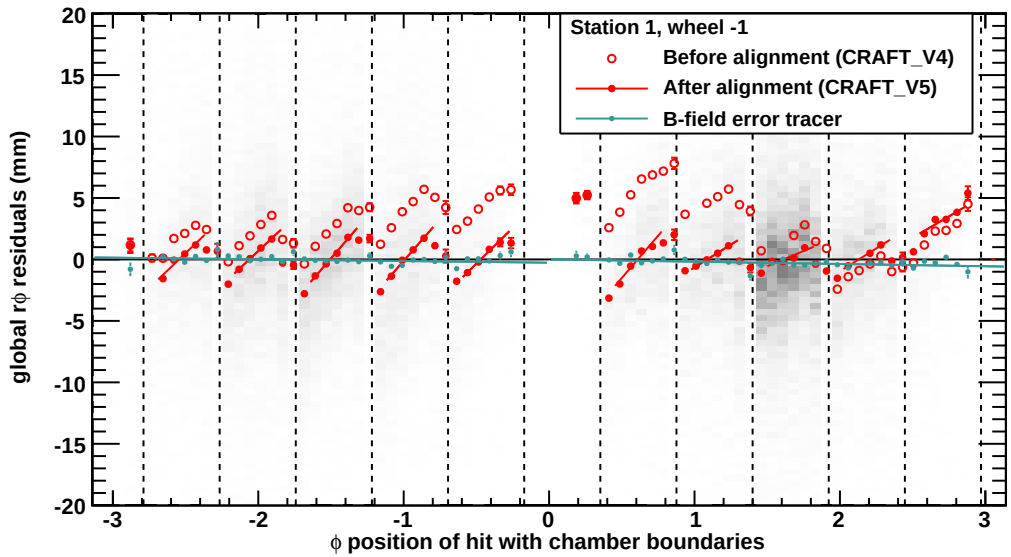
$$\text{“}x_0\text{”} \rightarrow \delta x + \phi_z\, y + \delta z\, \frac{dx}{dz}$$

- Consistent treatment that's easy to diagnose with plots

Is it a real alignment?

- We want to find the real positions of chambers, not just minimize residuals
- To look for biases in the track source, plot residuals more finely than the chamber boundaries
  - bias can change residuals shape inside chambers and across boundaries
  - only misalignments can make discontinuities at chamber boundaries
- Cause of linear slopes in $r\phi$ vs. ϕ (bottom) under investigation
  (DTs stretched in x? tested ϕ_y and z-shift hypotheses. . .)

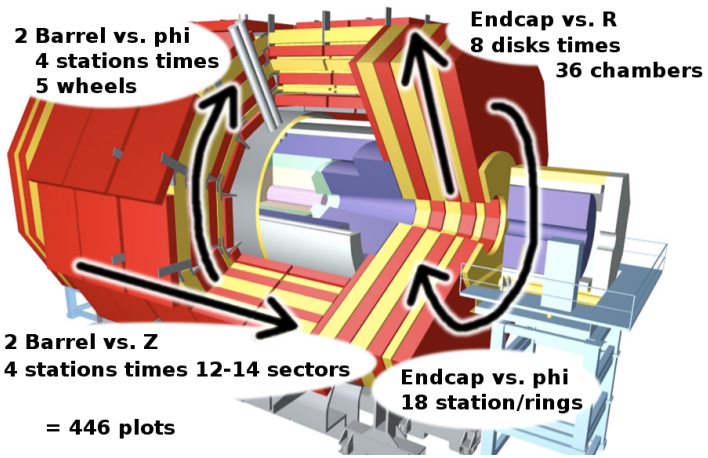


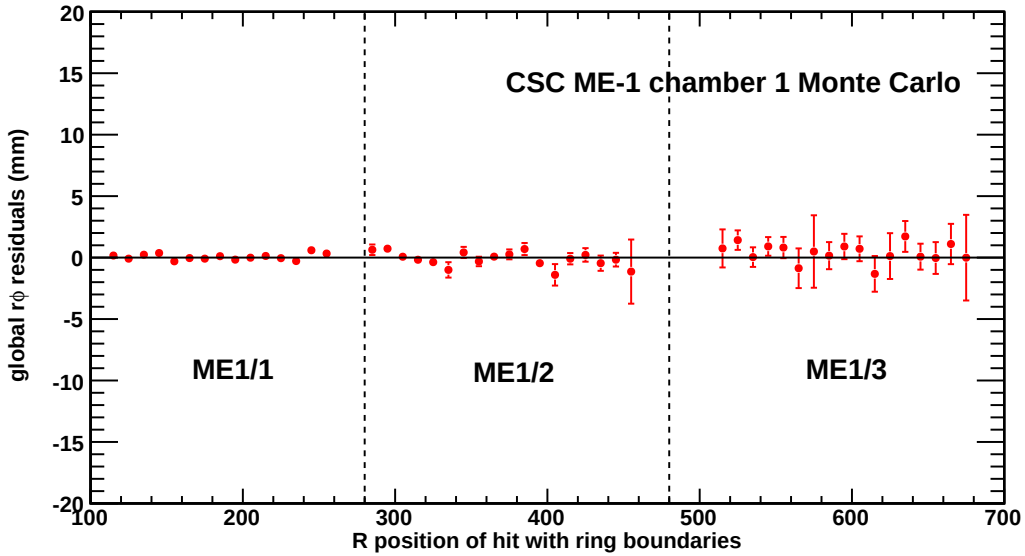


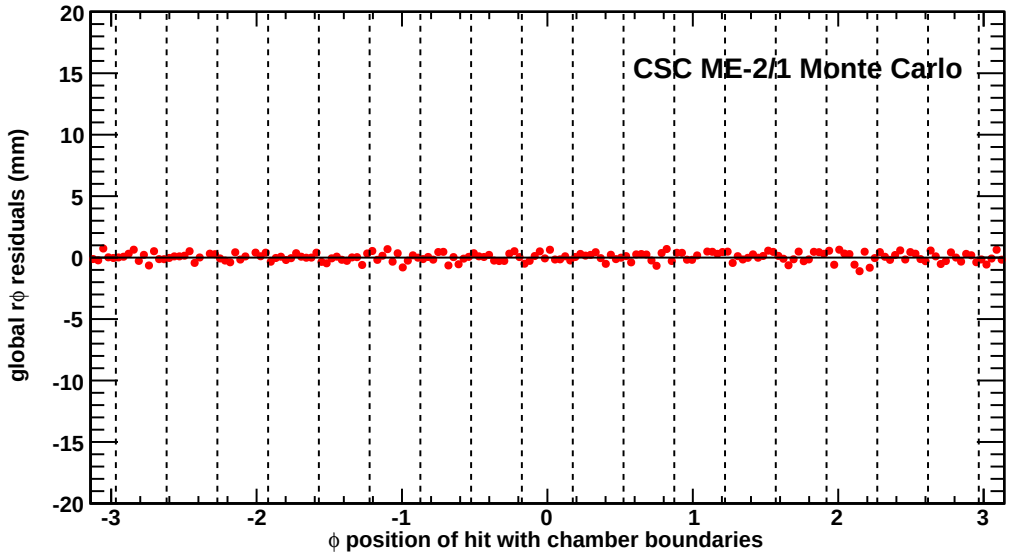
- Complete set of plots: http://indico.cern.ch/conferenceDisplay.py?confId=51267 ("more information")

Same thing for the endcaps

- Plot CSC residuals vs. R, rather than Z
  - note expected R^2 resolution dependence
- ϕ plots are similar to DTs



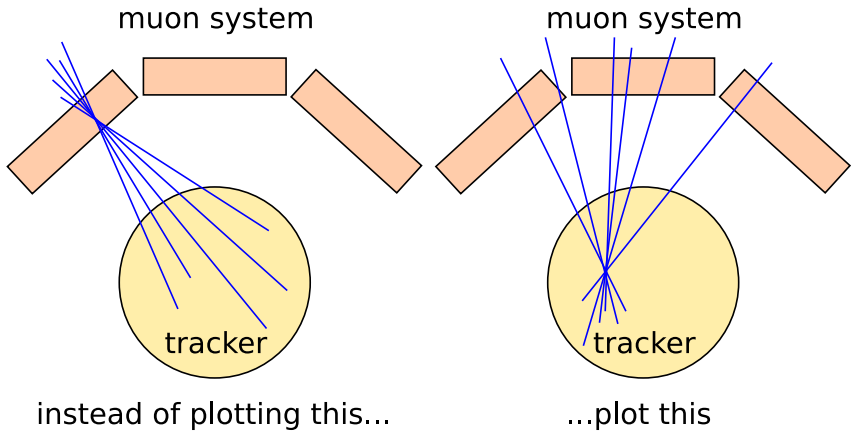




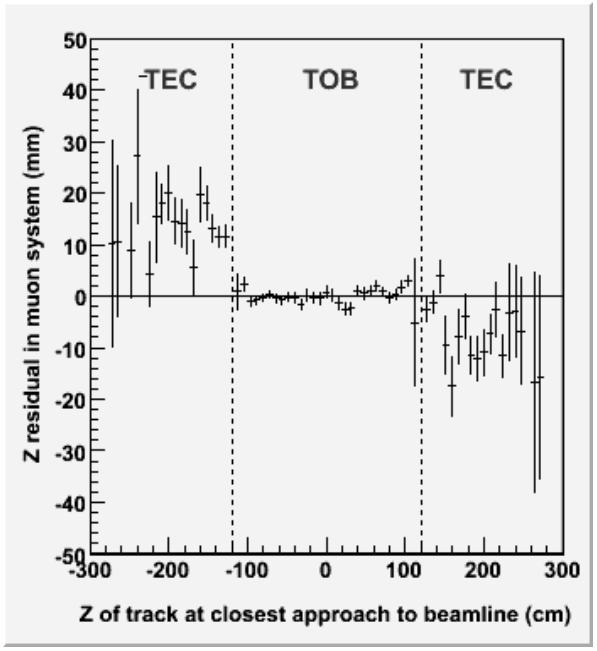
- Large number of diagnostic plots
- Future: must condense information into a few key validation plots

Tracker radiography

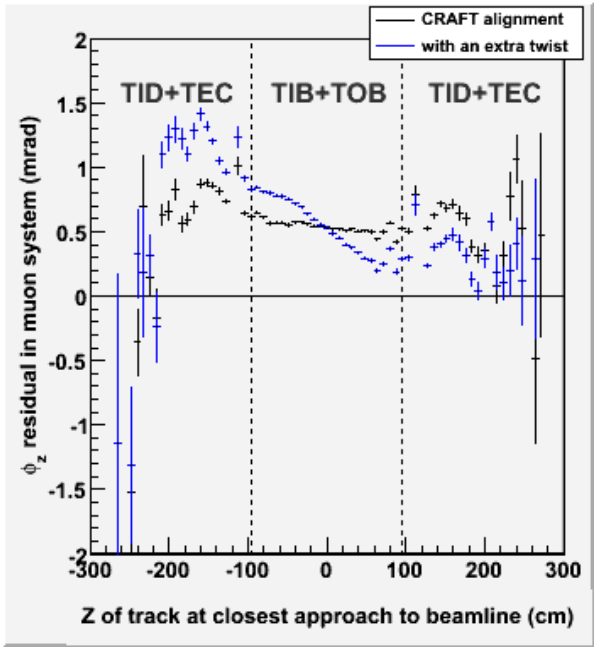
- Tracker misalignment or weak modes would bias muon alignment
- Non-projective cosmic rays allow us to investigate. . .



observation of TEC z misalignment (CRAFT_V4, not latest constants)

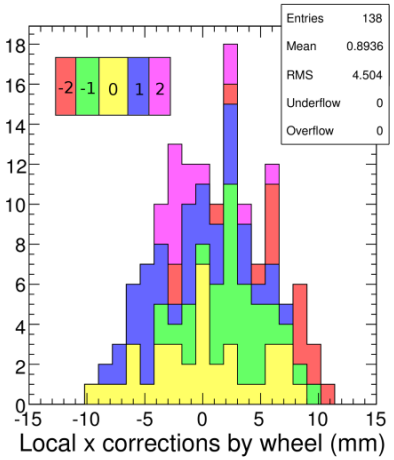


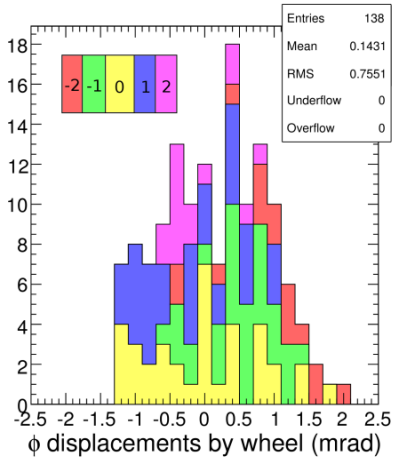
sensitivity study, tracker twist added by hand (blue)

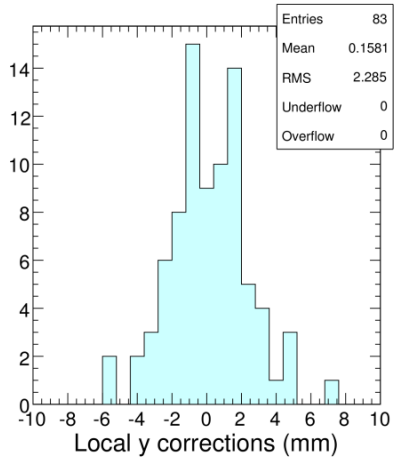


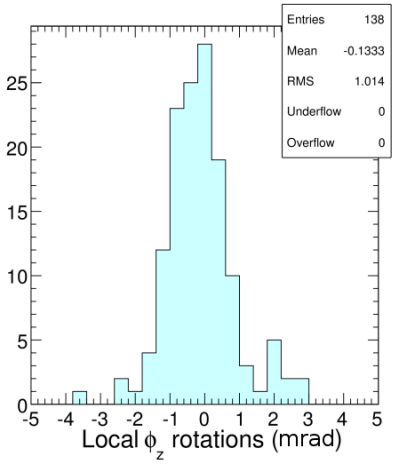
Barrel alignment results

- The following are alignment corrections used in CRAFT re-processing
  - local x is in the $r\phi$ direction, local y is along the beamline
  - x re-expressed as ϕ to demonstrate lack of wheel rotations

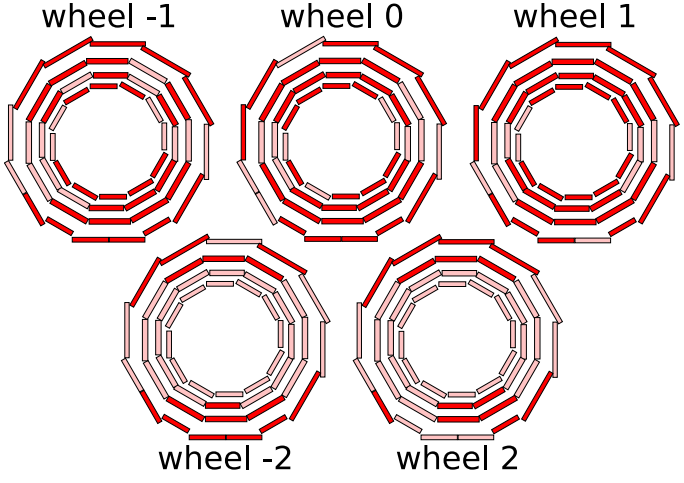




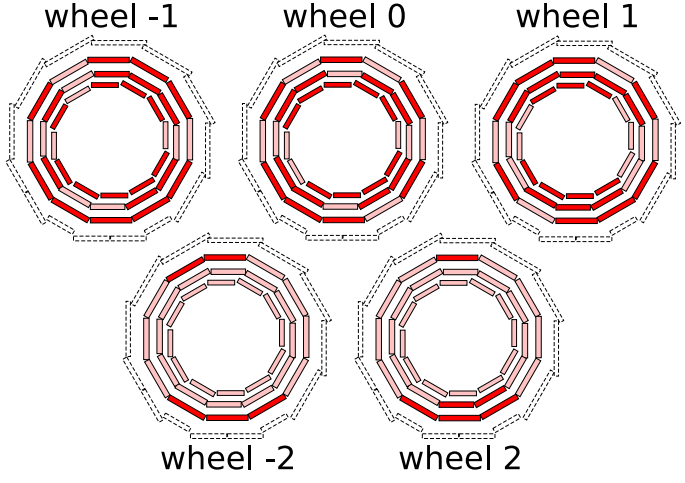




aligned in local x and ϕ_z:



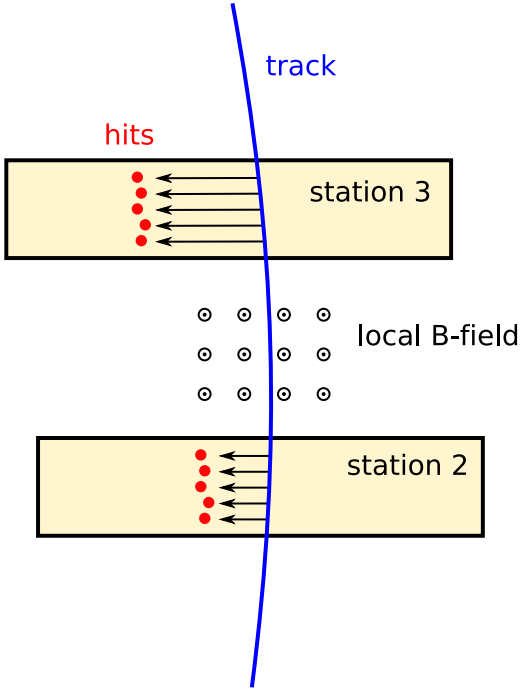
aligned in local y:

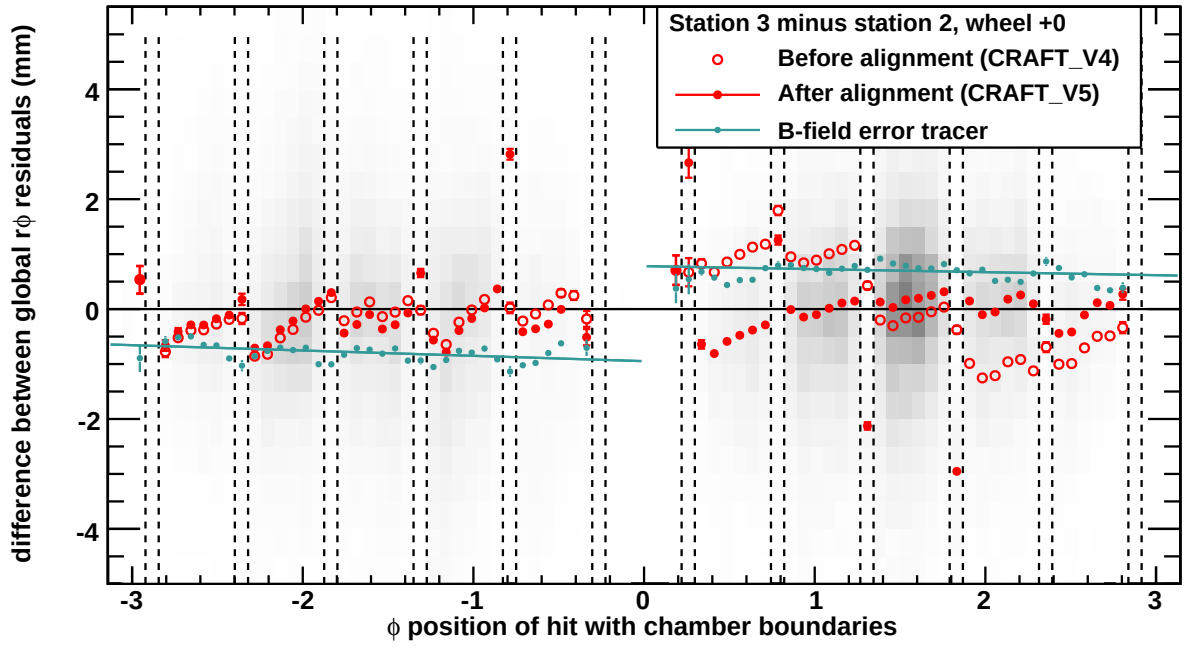


Cross-check: relative positions

- Alignment procedure determines chamber positions relative to tracker
- Chamber positions relative to other chambers is a true cross-check
- Difference of residuals on the same track uses the track as a curved ruler to compare two chambers:

$$\text{difference} = (\text{st. 3 track} - \text{st. 3 hit}) - (\text{st. 2 track} - \text{st. 2 hit})$$

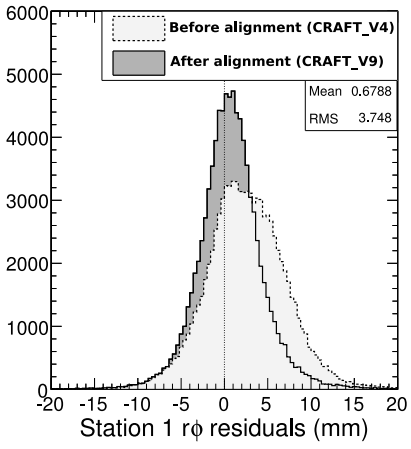


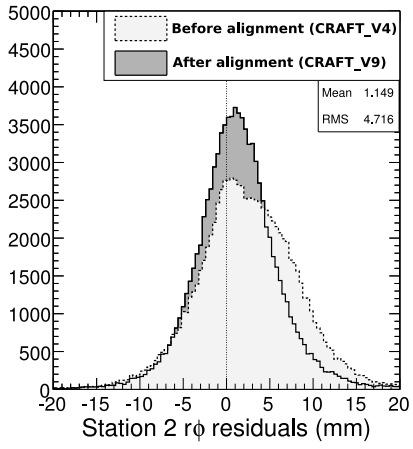


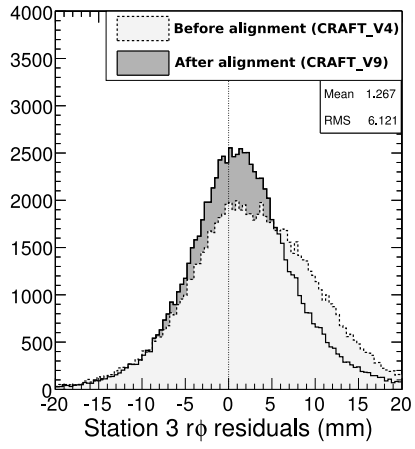
- Difference distributions are about 4 times narrower than residuals

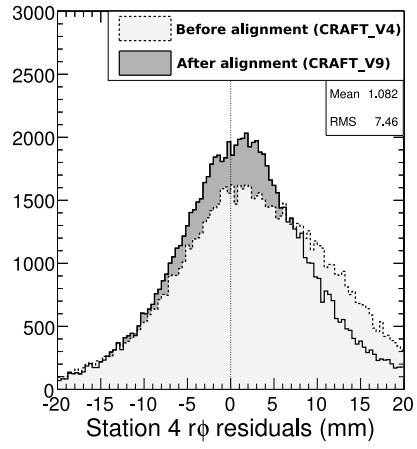
Residuals after barrel alignment

- Alignment narrowed and centered residuals distributions, as it must

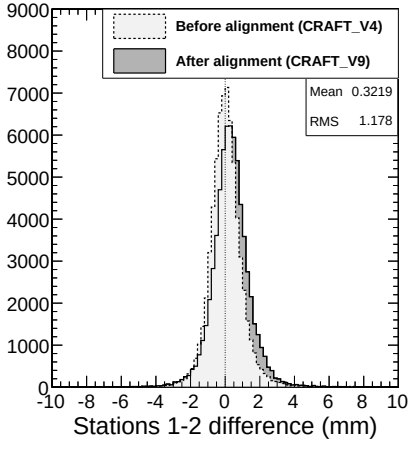


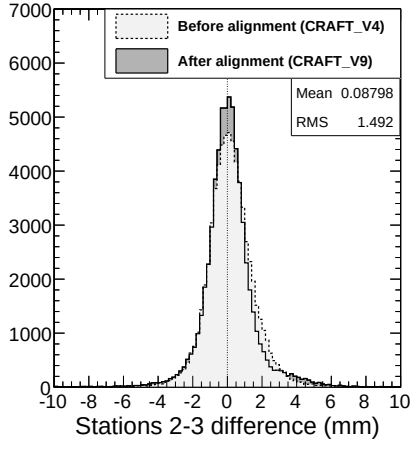


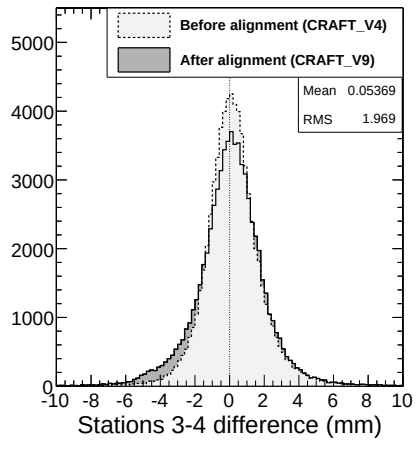




- Alignment preserved but didn't improve residuals differences
  - 1–2 mm *relative* chamber positions before and after alignment





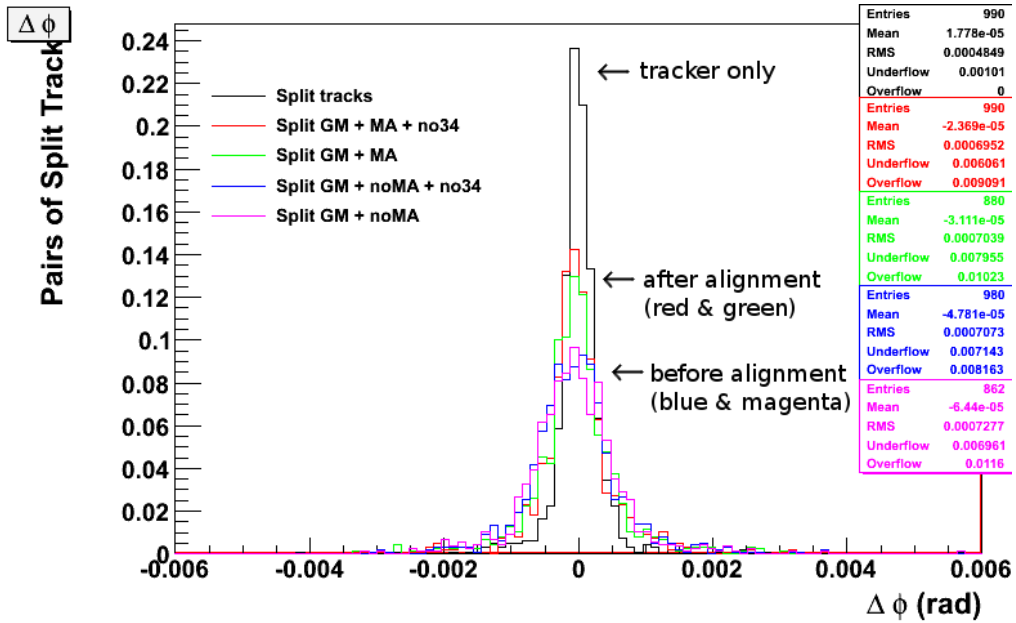


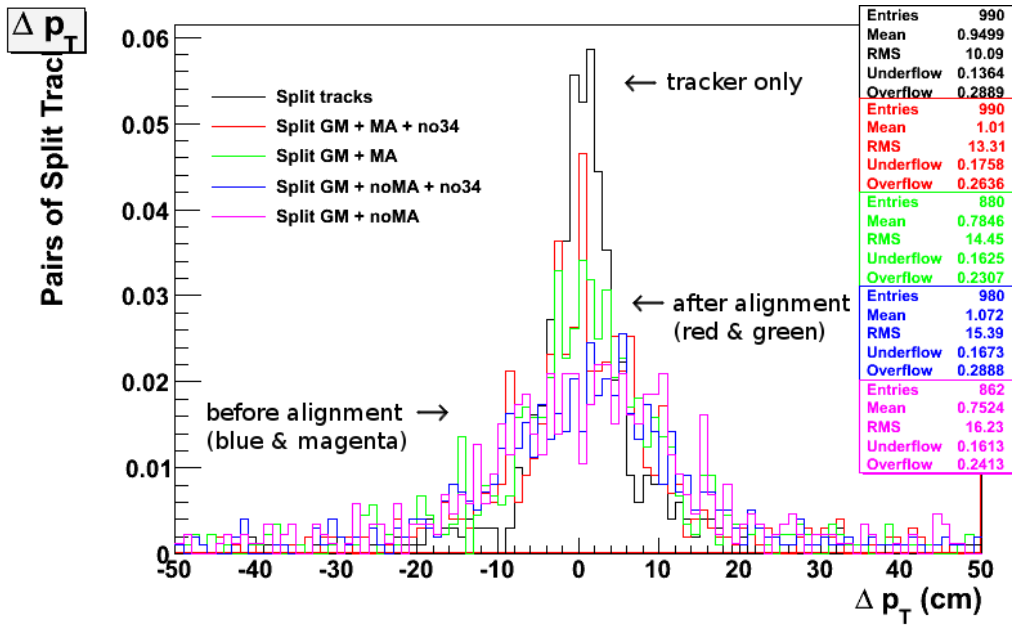
Note smaller scale

Cosmics track-splitting study

- Top and bottom half of a cosmic muon should have the same track parameters
- GlobalMuon resolution worse than tracker-only for three reasons:
  1. global misalignment
  2. magnetic field errors
  3. tracker given too little weight in global track fit
- Alignment improves matching of $p_T > 100$ GeV cosmics
  - insensitive to (2)
  - plotted before (3) corrected
- This is another cross-check because top-bottom agreement not used in alignment procedure

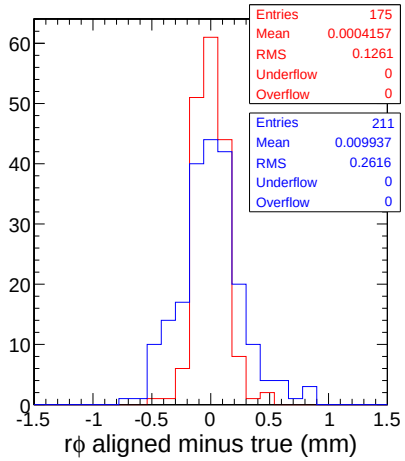
N. Tran, A. Bonato

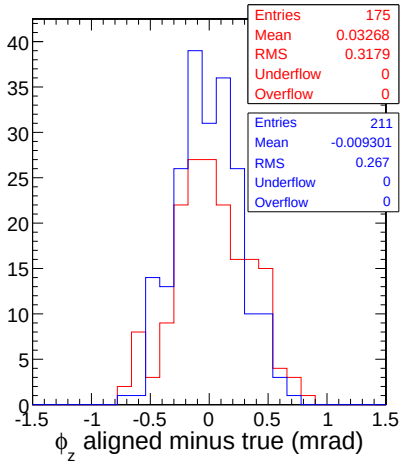


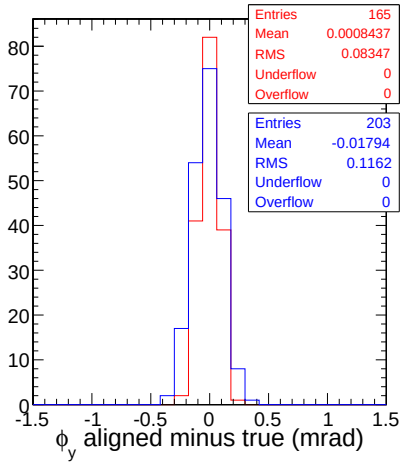


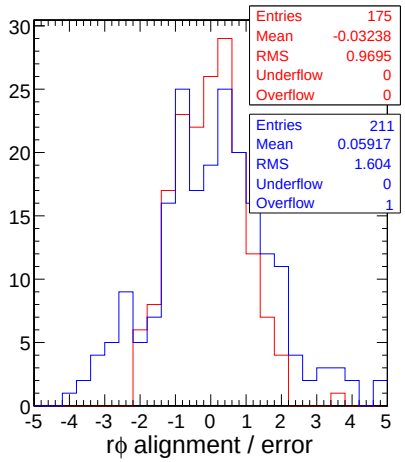
CSC alignment simulations

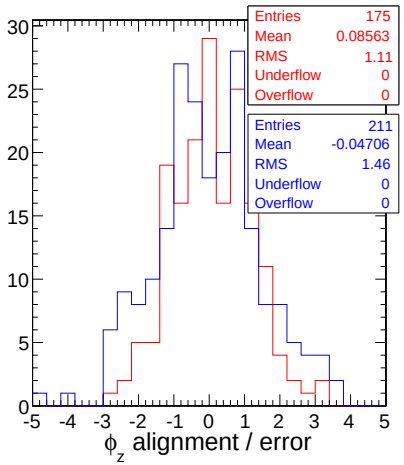
- 50 pb^{-1} of InclusiveMuPt10 (5× CSA08)
- Statistical only, early tests, but results scale as $\sqrt{N}$ from CSA08
- We now have reliable uncertainty estimates (see normalized distributions) and control for imperfect data: wrong $\vec{B}(\vec{x})$ and non-Gaussian tails

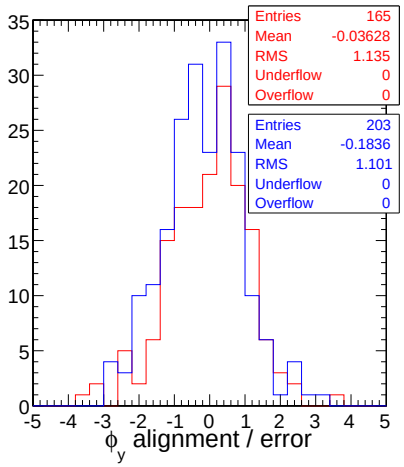












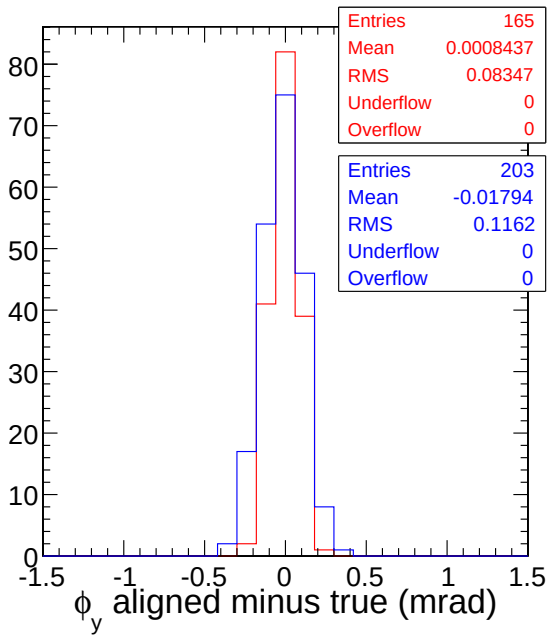
PRELIMINARY!
and statistical only

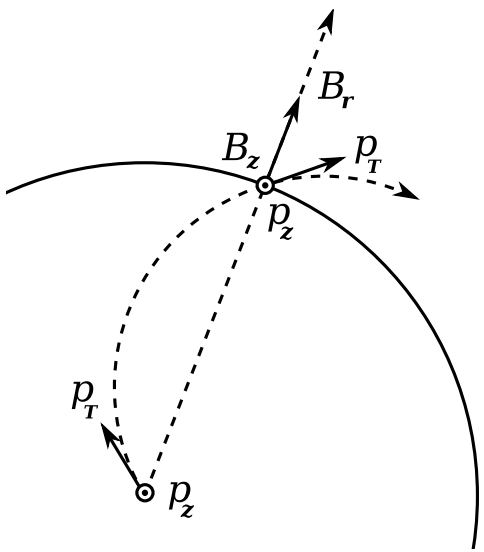
red is ring 1
130 μm

blue is ring 2
260 μm

z translation resolution under study

Synergy with $\vec{B}(\vec{x})$ studies

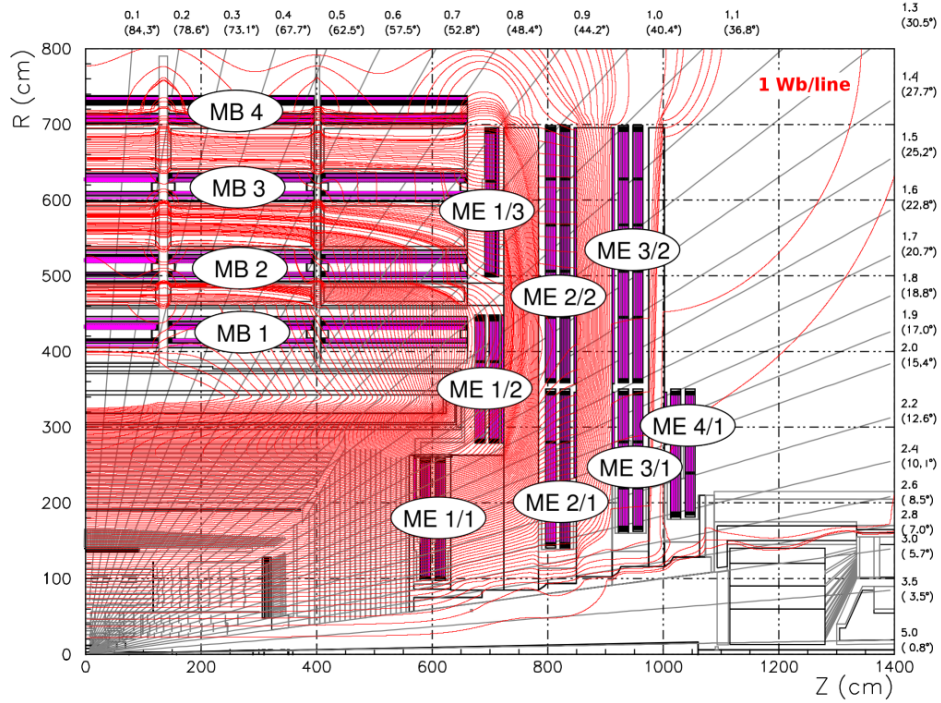




- Best-measured parameter, ϕ_y, is useful for measuring $\vec{B}(\vec{x})$ in the endcap

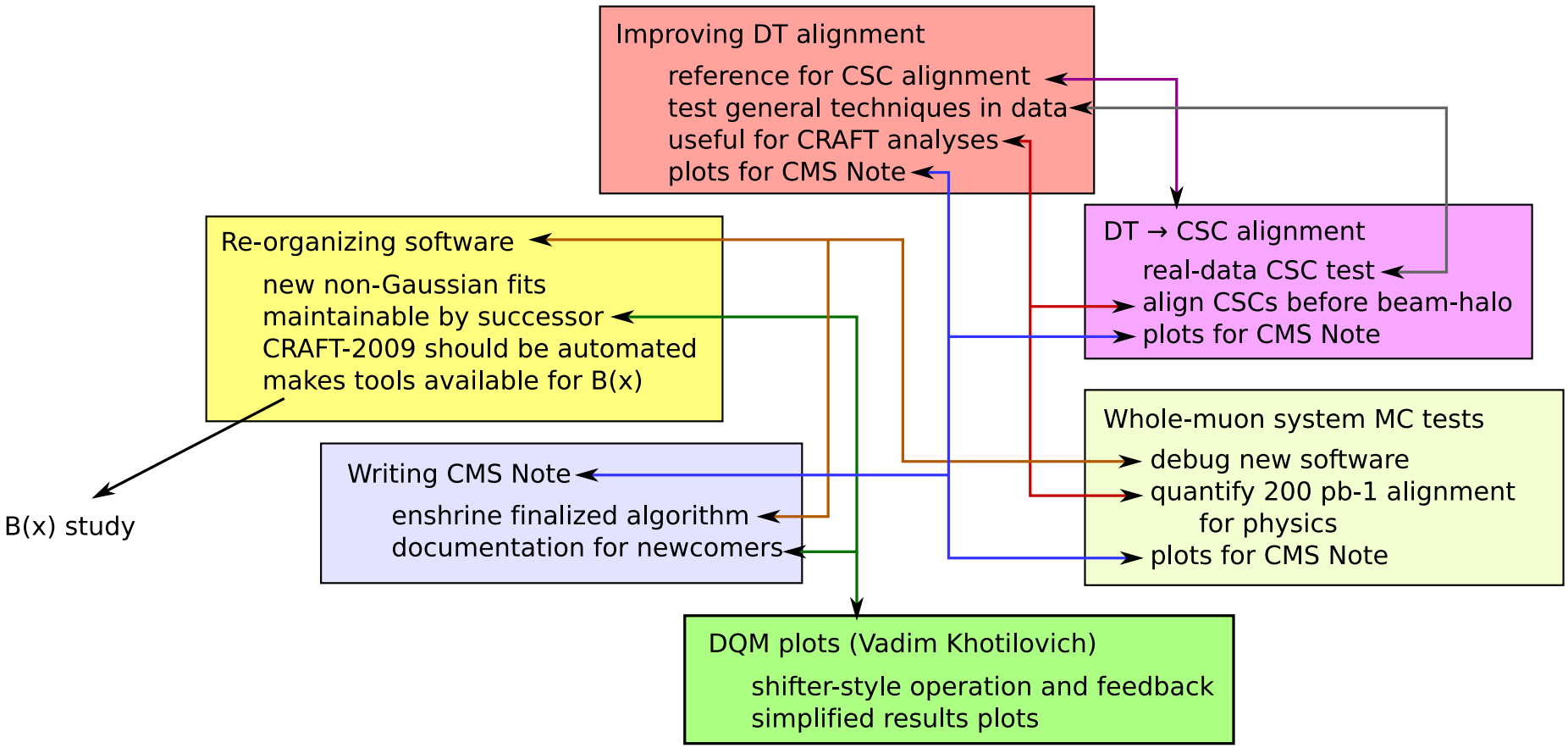
$$\Delta\phi_y \approx (\phi_y)_{\text{misalignment}} + \frac{R}{300 \text{ cm T/GeV}} \left[\left(\frac{q}{p_T} \right) \Delta B_z + \left(\frac{q}{p_z} \right) \Delta B_r \right] + (dE/dx \text{ error}) \frac{q}{p^2}$$

- We'll need it: endcap $\vec{B}(\vec{x})$ is complicated...

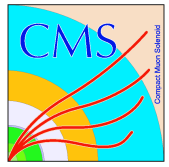


How do projects fit together?

- The following are in progress or will be soon Goal: end of June
  - whole muon system alignment for CRAFT-2008 analyses
  - automated software/plots ready for CRAFT-2009 beam-prep run
  - well-documented CMS Note to ease new-member transition
  - 200 pb^{-1} misalignment scenario for first physics analyses



Timeline for track-based

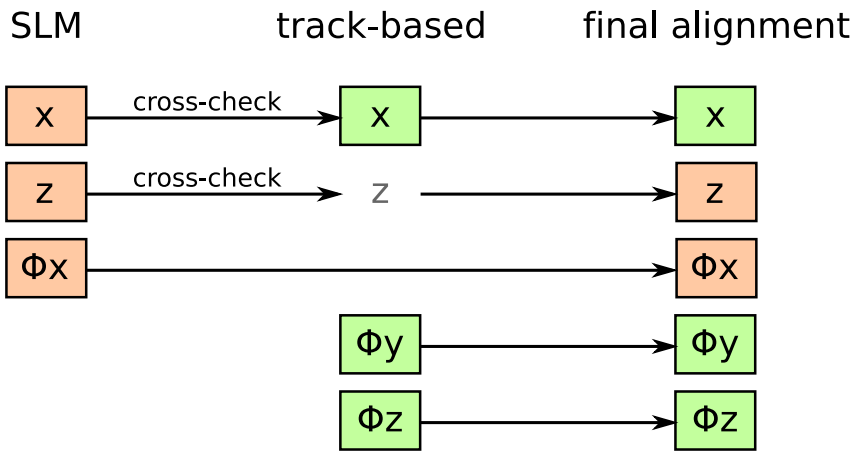


	Mar	
	Apr	Putting all the pieces together (prev page)
	May	Provide MC misalignment scenario for physics analyses
	Jun	
	Jul	Run CRAFT-2009 workflow: provide alignment quickly
	Aug	
	Sep	Run beam-halo alignment, align rings to tracker through cosmics
	Oct	Align CSC layers once-and-for-all with beam-halo data
	Nov	
2009	Dec	First collisions: resolve track biases by vetting
2010	Jan	collisions alignment against beam-halo/cosmics
	Feb	Determine optimal alignment procedure configuration
	Mar	Revise MC misalignment scenario estimate
	Apr	
	May	More routine operation: regular alignment results
	Jun	from final configuration
	Jul	
	Aug	Maybe think about high-statistics algorithms
	Sep	(e.g. $Z \rightarrow \mu\mu$ mass constraint) for 2011 run

Merging alignment information

- Every alignment procedure has parameters it measures well and parameters it doesn't
  - CSC Overlaps: x, ϕ_y, ϕ_z relative to ring
  - SLM: x, z, ϕ_x for monitored chambers relative to disk
  - Tracker-to-muon: x, z, ϕ_y, ϕ_z globally
- They can be sequentially chained if each does the following
  1. read a geometry from a CSCAlignmentRcd
  2. modify what it measures well by relative transformations
  3. write the updated geometry to a CSCAlignmentRcd

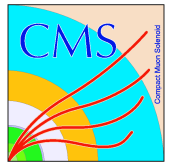
Simplified example: suppose it is determined that SLM z information is more accurate than track-based (through extensive cross-checks)



Much easier to understand the systematics of the final alignment and estimate its uncertainty for physics analyses

Global fit would obscure that

Conclusions



- CRAFT taught what real data looks like with high statistics
  - tested new techniques to disentangle $\vec{B}(\vec{x})$ effects from misalignment
  - got to know our residuals better
  - discovered a strange feature in $r\phi$ residual versus ϕ (page 10)
  - could only study DTs so far because there's a tracker $\longrightarrow$ DT $\longrightarrow$ CSC dependency with cosmic rays
- Produced a partial barrel alignment (and corresponding MC misalignment scenario) for physics analyses, passes cross-checks
- Consolidating experiences into revised software, documentation, and an updated estimate for resolution at 200 pb^{-1}
- CRAFT-2008 was about learning a new environment; CRAFT-2009 should be routine
- We'll have more to think about with first collisions, but cross-checks/systematics-study era will give way to routine era